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AN IMPORTANT FACTOR IN SPACE PERCEPTION IN THE PERIPHERAL FIELD OF VISION

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Two important reasons may be given for the poor space perception in the peripheral field of vision; defective imagery and a poorly developed sensorium. With reference to the relative importance of these reasons or factors, the concensus of opinion seems to incline to the latter. In a recent paper,[1] the belief is expressed that the refractive condition in the peripheral field can not play an important rôle because refractive errors in central vision do not seem to have very much effect on the space perception in the peripheral field. In this opinion the fact seems to be overlooked that as compared with central errors of refraction, the errors in the peripheral field are so great that not much effect could be expected. They modify the type of error found in the peripheral field, it is true, but clearness of imagery depends upon the amount rather than the type of defect.

It has been the purpose of the present experiments to study the refractive conditions in the peripheral field. One of the reasons for making this study is the bearing of these conditions on the explanation of the peculiarities and anomalies of peripheral space perception. Other important incentives have been their relation to acuity in the peripheral field; to achromatic and chromatic sensitivity in peripheral vision and to the limits of the form and color fields; their possible relation to defects of imagery in the central field and to ocular deviations; and the information which they give as to the position of the lens and the symmetry of conformation of the retina. In a later paper results will be given which bear still more directly on the importance of the refractive conditions in the peripheral field as a factor in peripheral space perception.

With reference to the above needs or any needs of practical application, the attempts that have been previously made to refract the eye for the peripheral field are unsatisfactory for the following reasons: (a) the methods used were either unsatisfactory as to accuracy or so cumbersome as to ap-

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[1] M. J. Zigler, B. Cook, D. Miller, and L. Wemple, The perception of form in peripheral vision, this JOURNAL, 42, 1930, 246-259.

paratus and procedure as to be worthless for practical work; (b) the results were not expressed in a form that has practical meaning or value; and (c) the determinations extended but a short distance into the peripheral field. A very important part of our purpose in making the study reported in this paper has been, therefore, the development of a method that will permit of determinations in the more remote parts of the field, that will be reasonably satisfactory as to accuracy and feasibility, and that will give results directly in terms of diopter values.

The two most important factors in the ametropia for the peripheral field are (1) the effect of the oblique incidence of the rays of light from objects in the peripheral field on the clearness of the image formed; and (2) the effect of size and shape of the eyeball and of anomalies and irregularities in the conformation of the retina on the distance of the percipient elements from the nodal point of the refracting system. With reference to the first of these factors it will be remembered that clear images are formed by lenses only when the object to be imaged is located on the principal axis of the lens. When the object is displaced from the principal axis a distortion of the image occurs which varies in amount with the angle of displacement of the object or with the angle of incidence of the light on the lens. In general, the effect of varying the angle of incidence is that of adding a weak plus sphere and a strong plus cylinder with its axis at right angles to the plane of incidence. The major effect is thus to create a strong astigmatism. A simple formula for this effect in the two meridians may be expressed as follows:[2]

$$F_1 = F(\mu - 1)/(\mu \cos b - \cos a)$$
$$F_2 = F_1 \cos^2 a$$

In these formulas F represents the focal length of the lens in question; F_1 the focal length in the meridian of least refractive power; F_2, the focal length in the meridian of greatest refractive power; a, the angle of incidence of the light; b, the angle of refraction at the first surface; and μ, the refractive index of the lens. In both meridians, then, the image is brought nearer to the lens as the angle of incidence increases, very much nearer in the meridian of the oblique incidence and very little nearer in the meridian at right angles to it. The refractive effect for the eye would thus be a slight [illegible]ia compounded with a strong myopic astigmatism. The effect on vision is modified, however, by the fact that the distance of the retina from the nodal point of the refracting system decreases rapidly as the distance from

2 Laurance, *General and Practical Optics*, 1908, 163-166, 3rd ed., 1920, 245-

the fovea is increased. In the greater number of eyes the effect of this is to bring the retina between the foci in the two meridians or to cause a mixed astigmatism which increases in diopter value as the periphery of the retina is approached. As will be shown later in the paper, however, other types of eye are also found, but they do not seem to be of such frequent occurrence.

Method and Apparatus

For the refraction of the eye for the peripheral field a Zeiss parallex refractionometer modified to suit our purpose was used. Like all the objective methods of refraction, the method used with this instrument provides a means of locating the point or plane which is the anterior of the pair of conjugate foci of the refracting system of the eye. Of this pair the fundus is the posterior focus. Also like the other objective methods—refraction with the ophthalmoscope and with the retinoscope—the method is only approximately correct in principle, *i.e.* the fundus and not the percipient elements is taken as the posterior focus. The reflecting surfaces which make up the fundus cannot be assumed to have the same location as the percipient elements nor even to sustain an invariable relation to them in the different parts of the eye ground and in different eyes. The distance between these reflecting surfaces and the percipient elements is minute, it is true, but in a refracting system as powerful as that of the eye even minute changes of distance in the posterior focus may become of consequence in the location of the anterior focus. The subjective methods of refraction alone start with the true posterior focus of the refracting system. This is one of the reasons why they should be the final court of appeal in making an accurate refraction.

The subjective method, however, we find, can be used with but indifferent success in the peripheral field. Of the objective methods, that used with the parallex refractionometer has thus far been found by us to be the most satisfactory for this work.

In brief, the principle of locating the anterior of the conjugate foci of the refracting system of the eye utilized in the Zeiss refractionometer is as follows. At the principal focus of the objective lens of the instrument is placed a transilluminated test object. The rays of light from this test object are collimated by the lens and enter the pupil of the eye as a parallel beam. If the eye is emmetropic the image will be focused on the fundus (approximately). Likewise when the eye is emmetropic the light reflected from the fundus will emerge from the pupil of the eye as a parallel beam and will be focused by the objective lens of the instrument at the position of the test object. In order to be able to compare the distances of the test object and of the image so formed from the objective lens of the instrument, the principle of parallax is used; that is, the line of view of the examiner is displaced slightly to one side of the principal axis of the refracting system of the eye and objective lens. If the distances of object and image from the objective lens are equal, the image will superimpose on the test object and will not be visible (emmetropia). If it is nearer to the lens than the test object, the image will be seen displaced to one side of the test object, the side towards the illuminating tube of the instrument (myopia); if it is further from the lens than the test object, it will be seen displaced to the other side, the side opposite the illuminating

-ube of the instrument (hyperopia). In order to provide for the refraction of the eye in different planes in the examination for astigmatism, the system can be rotated through 180° and the determinations made at any position within this range. In case the position of the test object and of its image are found not to coincide, the test object is moved until exact coincidence is obtained. The vertex refraction can then be read from a scale which is seen just above the test object. For a more detailed description of the instrument, the reader is referred to the circular issued by the manufacturer.

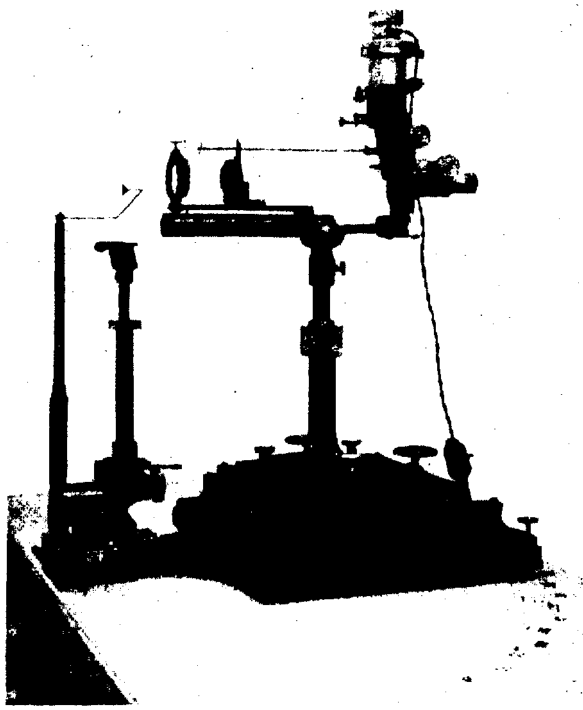

FIG. 1. MODIFIED ZEISS PARALLAX REFRACTIONOMETER

As the instrument is placed on the market, it is designed only for refraction at the center of the field. As modified by us, it can be used at any point in the horizontal meridian from the center of the field to an eccentricity of 60° temporally and nasally. Beyond this point the image reflected from the fundus is too dim to be distinguished. The instrument as modified for our purpose is shown in Fig. 1.

As seen in Fig. 1, the instrument is mounted on a carriage provided with ball and socket casters and made to pivot about a fixed point. The circle described by the carriage is graduated in degrees. The position of the carriage is read by means of a pointer which is located at the back of the carriage in the vertical plane passing through the principal axis of the optical system of the instrument. This pointer passes over the graduated scale. In order that the eye may be located with precision vertically above the fixed point and thus be at the center of rotation of the instrument, a small disk is mounted at the point of intersection of the perpendicular erected at the fixed point with the principal axis of the optical system. When the eye is in position the front of the closed lid is in contact with this disk. To maintain the eye in this position, the observer is required to bite a mouthboard in which the impression of his teeth has previously been made and hardened in wax. The disk is then turned out of the way.

In order to facilitate the location of the eye in the desired position, the mouth board is mounted on a rest provided with up and down, back and forth, and right and left adjustments. The adjustments are made by coarse-threaded screws. The screws for the right and left and the back and forth adjustments are driven by small wheels; the screw for the vertical adjustment is operated by a large milled head.

Method of controlling fixation and accommodation. It is supposed to be possible to use the instrument both with and without a cycloplegic. Both of these conditions have been used in this work. The directions given in the descriptive circular referred to above for the refraction of the central field without a cycloplegic are as follows: The patient is directed to look into the instrument with the eye under examination and to fixate the bright clear spot seen in the center of the field. This is for the control of fixation. For the control of accommodation the test target, which becomes clearly visible when it is located at the patient's far point, is always moved from a position beyond the far point towards the far point. The intention of this is to cause the patient to relax his accommodation in the interest of clear seeing.

We have not found this method to be entirely satisfactory. More reproducible results were obtained and results that check better with the subjective methods of refraction, by enlisting the aid of the eye not under examination; that is, by the use of both eyes, better control could be exercised over both fixation and accommodation. The procedure is as follows. When central refraction is to be determined, the eye not under examination is required to look at the smallest detail it can discriminate on a test chart at a distance of 6 meters. If it is hyperopic or emmetropic, it is fogged to 0.50 diopter of myopia to induce relaxation of accommodation. If it is myopic, it is already fogged for distance. In that case a larger detail to be discriminated has to be selected on the test chart. To guarantee that the eye not under examination is taking the same fixation as the eye under examination when it is looking at the bright dot at the center of the test field, as is required in the use of the instrument, the test chart is so located that the bright spot is seen at the center of the detail which serves for the fixation of the eye not under examination. This satisfies the two essential conditions; namely, that the two eyes are fixating in proper coördination and that the eye under examination is fixating the bright dot at the center of the test field. In refracting for the peripheral field the eye under examination can not, of course, be caused to look into the instrument. In this case both eyes fixate the distant chart whenever possible. This was possible only from 25° to 60°. That is, for the range 0° to 25°, when the temporal field was being refracted, the instrument was interposed between the test chart and the eye under examination. The fixation then had to be maintained by the either eye alone. For the range 0° to 25°, when the nasal field was being refracted, the instrument was interposed between both eyes and the test chart. In this case the effect of distance was given to the eye not under examination by mounting close in front of it a small test letter placed at, nearer or beyond the principal focus of a double convex lens, thus causing the rays of light from the lens to enter the eye parallel, diverging or converging as desired. Coördination of fixation for the zero position of the instrument was secured by locating the object and the bright spot in the instrument in such relation that the test objects presented to the two eyes were seen as combined in the median plane. When a cycloplegic was used, the procedure was the same, with the exception that the fixating eye was not fogged.

With the eyes in position and the fixation held as described above, the refraction of the eye was determined at the center and in the nasal and temporal quadrants of the horizontal meridian at intervals of 5° and 10° out to 60°. At each angle of incidence tested, the refraction for both the horizontal and the vertical planes was recorded, *i.e.* the refraction in the plane of the incidence of the light and in the plane at right angles to it. The error of the determination was approximately 0.25 diopter in the central field and the mid-periphery, and approximately 0.37–0.50 diopter in the far periphery where the reflected images, owing to the high degrees of astigmatism present, were indistinct.

RESULTS

A consideration of the effect of obliqueness of incidence on the refracting powers of a lens would lead one to expect a condition of myopia in the plane corresponding to the plane of incidence in case of an emmetropic eye with its refracting system symmetrically disposed in relation to the line to sight; that is, the effect of the oblique incidence in this plane is that of a strong plus cylinder. What the condition would be in the plane at right angles to the plane of incidence would depend upon two factors: (a) the effect of the obliqueness of incidence upon the focus in this plane, which, as already stated, is equivalent to that of the addition of a weak plus sphere; and (b) the shape of the eyeball. In proportion as the eye is spherical in shape, the retina from center to periphery is brought closer to the nodal point of the refracting system. In an emmetropic eye, therefore, with a symmetrical refracting system, one would expect a condition of hyperopia in this plane beginning at a point comparatively near the center of the field. At some point in the periphery in this type of eye a condition of mixed astigmatism might be expected. A mixed astigmatism might be expected also in case of small refractive errors at the center, hyperopic or myopic. In case of a sufficient amount of myopia at the center, a condition of compound myopia might be found in the periphery and similarly a condition of compound hyperopia in the periphery where a strong hyperopia is present in the central field. Obviously it is also possible that the shape of the curve of the eyeball from the posterior pole towards the equator may be such as to cause either a compound myopia or a compound hyperopia even when there is only a slight error of refraction at the center. In this connection it should be remembered that in case of such a strong refractive system as is found in the eye, a very small difference in distance of the retina from the nodal point is sufficient to cause several diopters difference of myopia or hyperopia as the case may be.

Twenty-one eyes were examined in all, 15 without and 6 with a cycloplegic. The amount of refractive error at the center varied among these eyes from 0.25 diopter of astigmatism to several diopters of defect. In general, the effect of oblique incidence was an astigmatism which was variously modified in the eyes examined by the distances of the percipient elements from the nodal point of the refractive system. Classified as to peripheral refraction, 3 types of eye were found. In one type, A, the eye becomes more myopic in the horizontal plane as the periphery of the retina is approached, and more hyperopic in the vertical plane. That is, the curve representing the refractive errors for the horizontal plane tends downward as the periphery is approached and the curve for the vertical plane tends upward. In all the cases but one in which there was a high myopic astigmatism (central refraction), this resulted in a mixed astigmatism in the peripheral field, the interval of Sturm varying over a considerable range of diopters. In a second type, B, the eye becomes less myopic in the horizontal plane as the periphery of the field is approached and more hyperopic in the vertical plane; that is, the trend of the curve for both planes is upward. In the cases studied this resulted in a condition of compound hyperopia in the peripheral field for eyes that were hyperopic, emmetropic or moderately myopic in the central field. If strong myopia is present at the center it is obviously possible that a compound myopia might result over a greater part of the peripheral field. In a third type, C, the condition was asymmetrical, *i.e.* a considerable difference was found in the nasal and temporal halves of the field.

The results are shown in Figs. 2–6. In the charts shown in these figures the results for the horizontal plane, the plane of incidence of the light, are plotted as a solid line; for the vertical plane, the plane at right angles to the plane of incidence of the light, as a broken line. Degrees of eccentricity are plotted along the horizontal coördinate and diopters of refractive defect along the vertical coördinate. The condition of no refractive defect is represented by a horizontal line drawn through the center of the chart. Diopters of hyperopia are plotted above this line along the vertical coördinate; diopters of myopia below it. The diopters of hyperopia and myopia are expressed in terms of the correction needed, + and — respectively. The

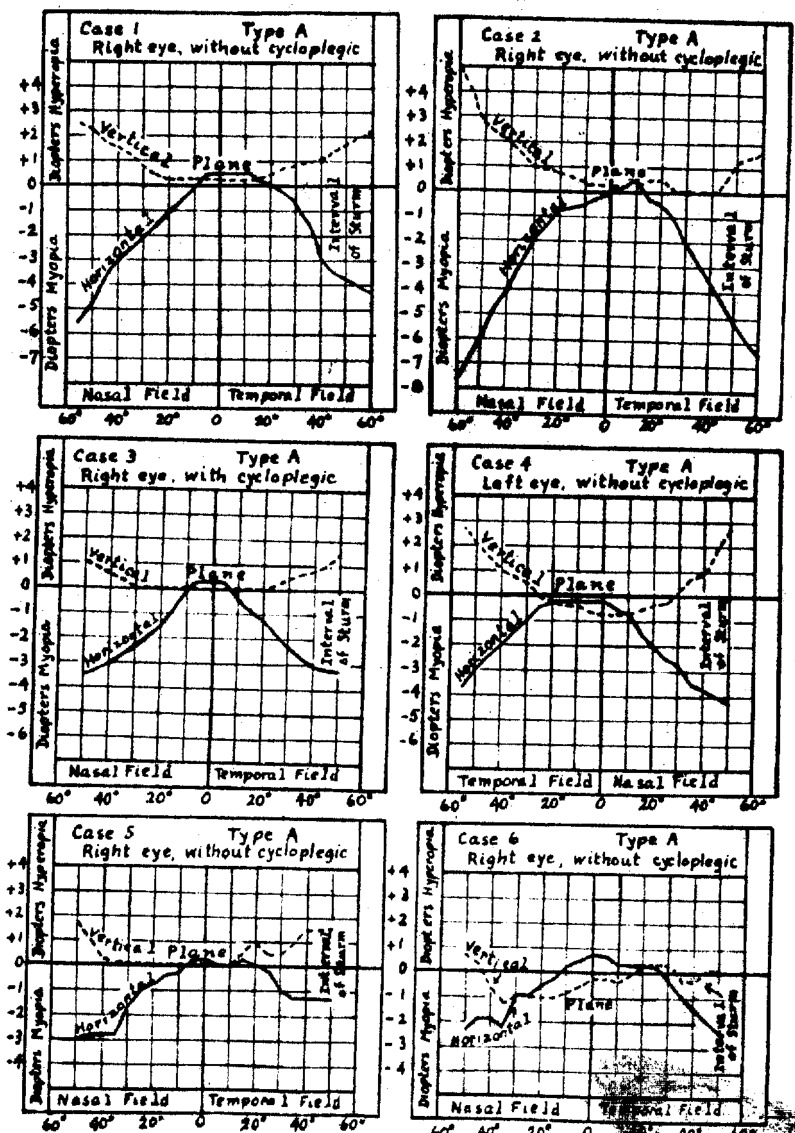

FIG. 2. REFRACTION OF PERIPHERAL FIELDS OF VISION FOR EYES OF TYPE A THAT HAVE ONLY A SLIGHT ERROR OF REFRACTION AT THE CENTER

value of the interval of Sturm can be read along the vertical coördinate at corresponding points between the solid and broken lines.

From the statement of principles already given, it is obvious that the shape of the curve drawn as a broken line is determined dominantly by the shape of the eyeball or by the distance of the percipient elements from the nodal point of the refractive system. That is, this curve represents the refraction in the vertical plane at the various points examined and the refraction in this plane is not strongly affected by the angle at which the examination is made. The shape of the curve drawn as a solid line, however, is strongly affected by the angle at which the examination is made. This curve represents the refraction in the horizontal plane, the plane of oblique incidence; and the effect is, as already stated, to bring the focus progressively nearer to the nodal point of the refracting system as the angle at which the examination is made is increased. The former curve thus informs us, roughly at least, as to the symmetry of conformation of the retina; and the latter, together with its relation to the former, gives us information as to the symmetry of action of the refracting system.

In Fig. 2 are shown results for 6 eyes of the class we have called Type A. These eyes all have only a slight refractive error at the center. It will be noted that in general the defect in the vertical plane, the amount of which is shown by the displacement of the broken line from the line of reference or zero line, is much smaller than the defect in the horizontal plane, shown by the displacement of the solid line. That is, the defect due to the obliqueness of incidence of the light on the refractive system is greater than the defect due to the progressive approach of the retina to the nodal point as the distance of the point under examination from the center of the field becomes greater. In short, in most cases much the greater part of the interval of Sturm is due to the astigmatism of oblique incidence. Some asymmetry will be noticed also in Case 6 but not enough to warrant placing it in the class which we have called Type C.

In Fig. 3 are shown the results for 6 eyes also of the class we have called Type A. These eyes have, however, a much more pronounced error of refraction at the center. The following points may be noted in connection with the results for this chart: (a) the curves are less regular; (b) the temporal and nasal halves of the curves are less symmetrical—Case 8, for example, shows so much asymmetry as to deserve, perhaps, to be classed as Type C; and (c) the point at which the mixed astigmatism begins is farther from the center of the field than is the case in Fig. 2—that is, a smaller proportion of the field carries a mixed astigmatism and a greater proportion a compound myopic or a compound hyperopic astigmatism. In Case 10, a

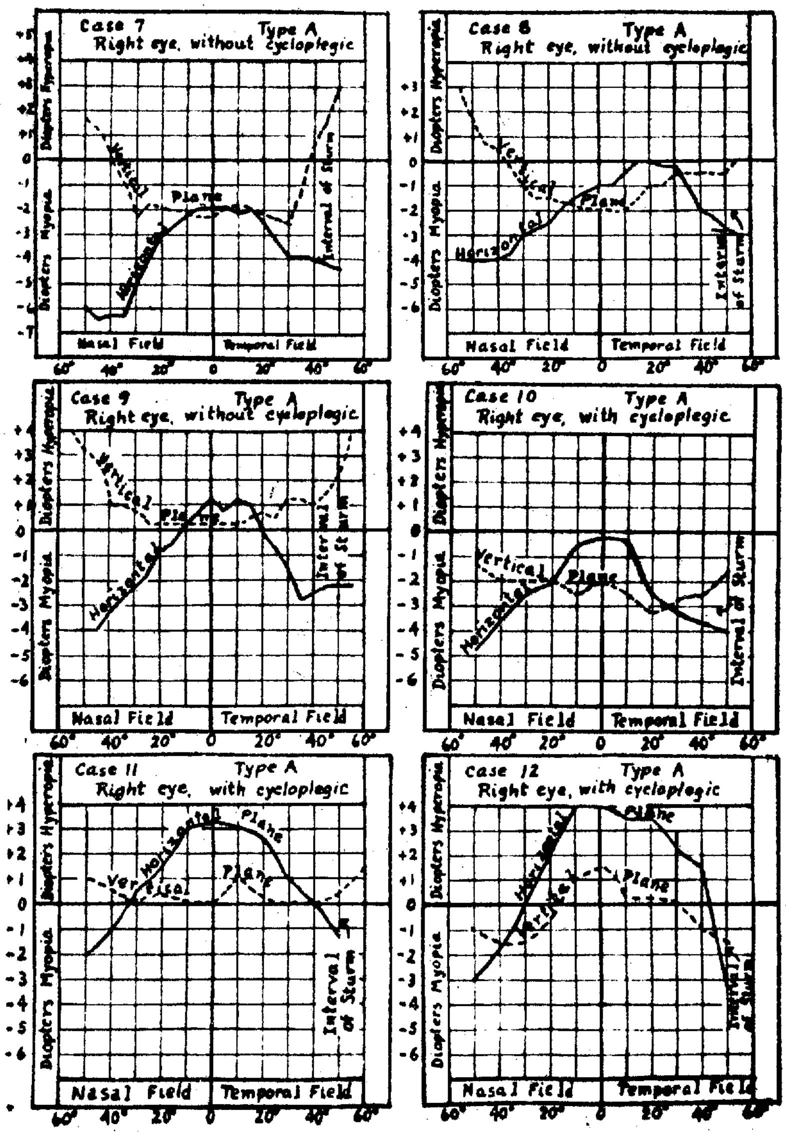

FIG. 3. REFRACTION OF PERIPHERAL FIELDS OF VISION FOR EYES OF TYPE A THAT HAVE A PRONOUNCED ERROR OF REFRACTION AT THE CENTER

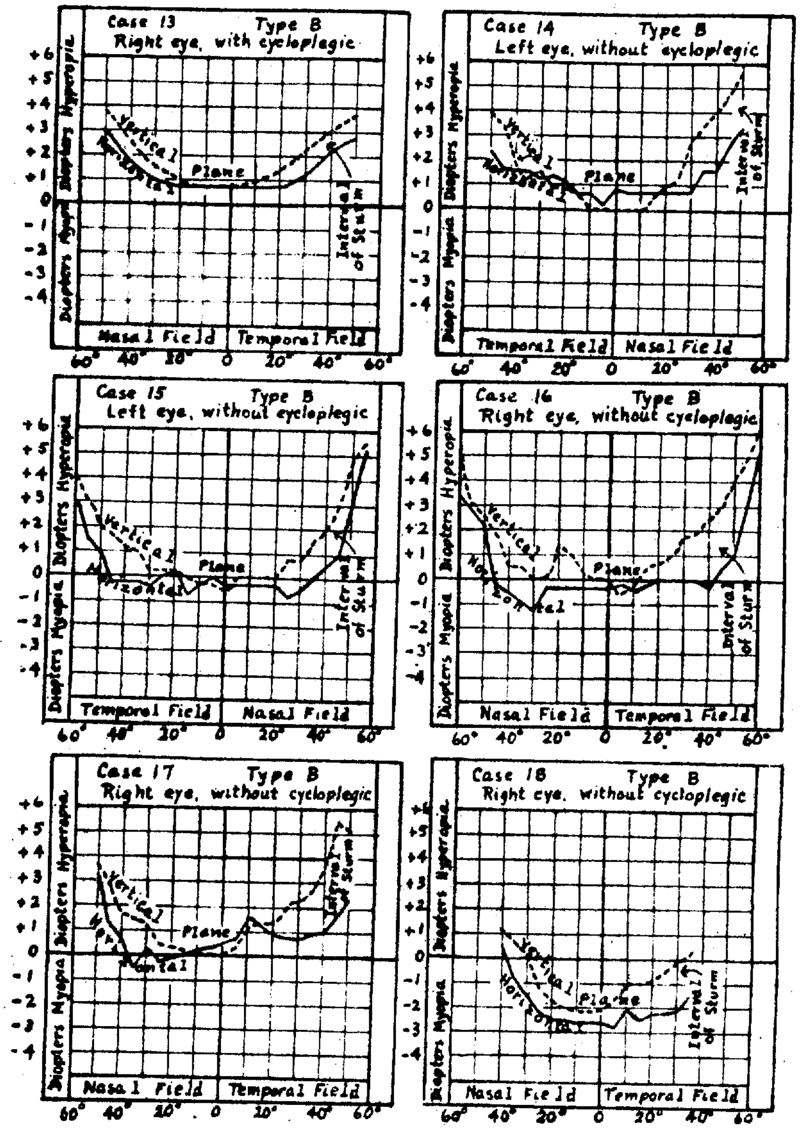

FIG. 4. REFRACTION OF PERIPHERAL FIELDS OF VISION FOR EYES OF TYPE B
Five have only a slight error of refraction at the center, one has a pronounced error.

compound myopic astigmatism with the greater myopia in the vertical meridian, the curves for the two meridians cross at approximately 20° to 25° from the center of the field; *i.e.* beyond these points the eye becomes more myopic in the horizontal plane and less myopic in the vertical plane, but it retains a compound myopia as far out as the examination was made. The astigmatism changed, however, from compound myopia with the rule to compound myopia against the rule.

In Fig. 4 are shown the results for 6 eyes which belong to the class we have called Type B. The characteristic defects in the peripheral field for these eyes are compound hyperopia and compound myopia. Four of the

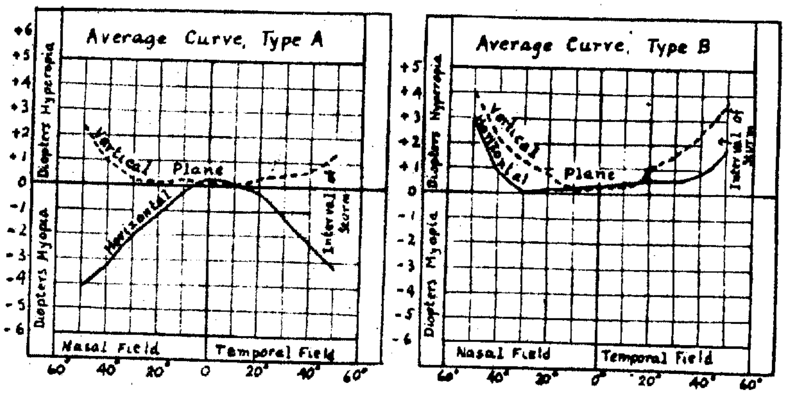

FIG. 5. COMPARISON OF THE RESULTS OF THE EYES OF TYPES A AND B

The chart at the left shows the average refraction of the eye for the peripheral field for 6 eyes of Type A having only a slight error of refraction at the center; that at the right, the average refraction for the peripheral field for 5 eyes of Type B having only a slight error of refraction at the center.

eyes have a slight refractive error at the center of the field and two a more pronounced error. As is shown in the chart, a striking feature of these cases is the smallness of the interval of Sturm in the peripheral field. In Type A the general trend of the curve for the vertical plane from center towards periphery is upward and of the curve for the horizontal plane downward. This gives a progressively increasing value to the interval of Sturm from center towards the periphery. In the cases of Type B, however, the trend of both curves from center towards the periphery is upward, the trend for the curve for the horizontal plane being less sharply upward. There is thus an interval of Sturm, but it is of smaller value than for the cases of Type A. It would appear that the astigmatism of incidence does not play proportionately so strong a rôle in the eyes of Type B as it does in the eyes of Type A.

In the left half of Fig. 5 are given curves showing the average of the results in the nasal and temporal halves of the field for 6 cases of the class we have called Type A. We have selected for this average only the cases which have a slight defect in refraction in the central field. This chart shows a slight asymmetry, i.e. in the nasal half of the field there is a greater amount of myopia in the horizontal plane and a greater amount of hyperopia in the vertical plane than there is in the temporal half of the field. In the right half of Fig. 5 are given average curves for the nasal and temporal halves of the fields for 5 of the cases we have called Type B. We have selected for the average curve here, also, the cases which have only a slight

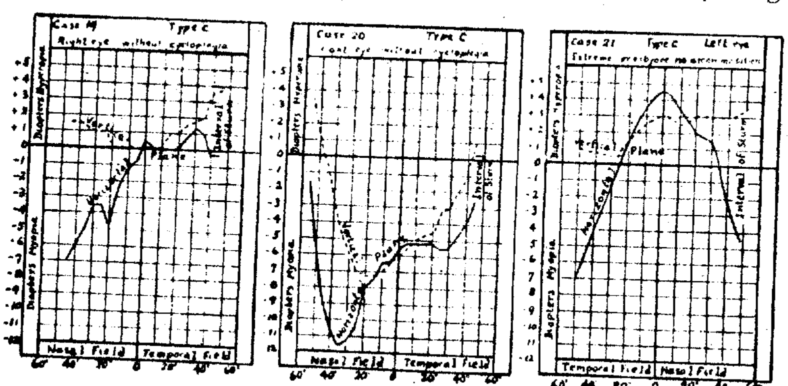

FIG. 6. REFRACTION OF THE PERIPHERAL FIELDS OF VISION FOR EYES OF TYPE C
These three eyes show marked asymmetry in the refraction of the nasal and temporal halves of the field.

defect of refraction in the central field. The average curves for the two halves of the field show less asymmetry, perhaps, than the curves in the left half of Fig. 5. Here too a greater refractive defect is shown in the nasal than in the temporal half of the field.

In Fig. 6 are shown the results for 3 eyes of the class we have called Type C. These cases, which show a pronounced difference in the two halves of the field, suggest (a) that the lens may not be symmetrically positioned with reference to the anterior-posterior plane of the eye; (b) that there may be asymmetry in the shape of the nasal and temporal halves of the eyeball in the meridian examined or a difference in the distance of the percipient elements from the nodal point of the refracting system in the two halves of this meridian from any cause whatsoever; or (c) that there is a combination of these two conditions. In the three cases shown in Fig. 6 a pronounced asymmetry was found in the refractive condition of the temporal and nasal halves of the field and in one of these, Case 21, the asymmetry may sustain a causal relation to the ocular deviation which was found to be present. In the other two cases the character of the asymmetry is not such as to lead one to suspect any considerable effect on the muscle balance of the two eyes.

An inspection of Case 19 of this chart shows little asymmetry for refraction in the vertical plane; that is, the two halves of the curve for this plane (the broken line) show little difference in shape. For the refraction in the horizontal plane there is, however, a great deal of asymmetry. Largely because of the asymmetry in refraction in the horizontal plane there is also a pronounced asymmetry in the interval of Sturm in the two halves of the field. Under test this case showed practically no muscle imbalance.

An inspection of the chart shows no reason for expecting a muscle imbalance, so far as the refractive situation, central and peripheral, is concerned. That is, the eye is nearly emmetropic at the center of the field and no deviation in either direction could be expected to improve the refractive condition. The curves for this eye would seem to indicate a fairly symmetrical eyeball in the meridian under examination but an asymmetrical refracting system. The general shape of the curve for the refraction in the horizontal plane is such as might be expected for a lens rotated or tilted towards the temple. That is, the focus for objects in the nasal field is shorter than for objects in the temporal field as would be the case if the angle of incidence of light on the lens from objects in the nasal field was greater than from objects in the temporal field.

Case 20, Fig. 6, shows a pronounced asymmetry of the nasal and temporal halves of the field, but it appears to be an asymmetry due to a very considerable extent to the elongation of the eyeball in high myopia. An inspection of the curve representing the refraction in the vertical plane, the curve the shape of which is dominantly influenced by the shape of the eyeball, shows the maximum of myopia at about 15° to the nasal side of the center of the field or at a point on the retina about 15° to the temporal side of the fovea. The diopter value of the myopia here is about 7.25, at the center of the field it is 6. From the point of maximum value the curve rises more sharply towards the nasal than towards the temporal side of the field. However, at corresponding points in the two fields the myopia is greater in the nasal than in the temporal field. It is interesting to compare the shape of this curve with the shape of the eyeball in high myopia as is shown by the cross section of the eyeball given in Fig. 7. In the horizontal plane the value of the myopia at the center of the field was 5.5 diopters; at 35° it reached a maximum in the nasal field of 11.5 diopters; at 45° in the nasal field it was 9 diopters and at 55°, 1.5 diopters. In the temporal field the value of the myopia at 30° was 5.5 diopters and at 45°, 2.5 diopters. A comparison of the shape of the two curves and of the interval of Sturm in the temporal and nasal fields indicates an asymmetry in the refracting system as well as in the shape of the eyeball, such as might be produced by a rotation or tilting of the lens towards the temple. The test both with the Maddox rod and with prisms shows 10 prism diopters of exophoria. When fixation was taken with the right eye alone, a deviation of 20° towards the temple was shown. Measurements of the cornea showed no asymmetry and the value of the curvature in both meridians fell within the normal range.

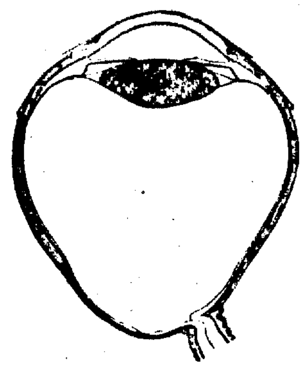

FIG. 7. CROSS-SECTION OF A MYOPIC EYE HAVING AN AXIAL LENGTH OF 28 MM. (From Fuchs: Textbook on Ophthalmology)

The color fields for red and blue, 1° stimuli, showed a contraction in the upper half. The field for 1° green was very small. The ocular deviation in this case was probably due to the high degree of myopia. Refractive asymmetry apparently had little or nothing to do with it. This may be inferred from the fact that when the myopia for the center of the field was corrected, the deviation practically disappeared and by the fact that a deviation of the eye either toward the temporal or the nasal side could not have been expected to render any very effective service in clearing up the defective imagery.

An inspection of Case 21, Fig. 6, left eye, shows asymmetry in the curves for both the vertical and horizontal planes. At the center of the field there was a high compound hyperopic astigmatism, 3 diopters in the vertical and 4.5 in the horizontal plane. In the nasal field in the vertical plane there was little change in the hyperopia as far from the center as 50°. In the temporal field it had decreased to 0.5 diopters at 25° and was 1 diopter at 50°. In the nasal field in the horizontal plane it decreased to zero at 35°; and at

50° there was 4.5 diopters of myopia. In the temporal field the hyperopia decreased to zero at 35°; and at 50° there was 7 diopters of myopia, just twice the amount present at the corresponding point in the nasal field. It is significant to note that the nearest approach to emmetropia in the eye came at 25° from the center in the nasal field. The defect here was 0.5 diopter of simple hyperopic astigmatism.

The vision in this eye was 20/200 and could not be improved substantially by correction. The patient stated that prior to 15 years ago there was, so far as he knew, no vision at all in this eye. An examination for central scotoma gave negative results. That is, while the test object was seen

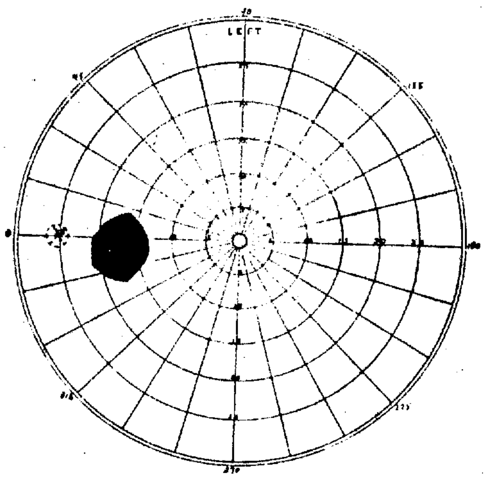

FIG. 8. BLIND-SPOT AND FIXATION-POINT FOR CASE 21

vaguely at the center it was seen equally clearly there and in the field surrounding the center for 15 degrees to 20 degrees in all directions. A test with the Haitz charts showed that when both eyes were open the vision in this eye was entirely suppressed. When the right eye was closed, however, the figure for the left eye in the chart was seen. When both eyes were open there was no observable deviation in either eye; but when the right eye was closed the left immediately turned inwards and took a fixation approximately 25° from the median plane. It will be remembered from Fig. 6 that the nearest approach to emmetropia in the left eye was at an eccentricity of 25° in the temporal field. When using this eye alone, the patient apparently turned the eye inwards about 25° in order that objects in front should be in the line of the least refractive error and the clearest image be formed on the retina.

In the course of the examination of the eye the blind spot was mapped on the tangent screen of the Ferree-Rand perimeter with a 0.5° white stimulus-object on a black background. With the eye turned towards the center of the arc of the perimeter, the fixation-object could not be seen with sufficient clearness to give a satisfactory control of fixation. In order to secure a correct fixation, the left eye was lined up by means of the telescope inserted in the hollow axle of the perimeter. A large fixation-cross, 3 cm. in diam., was moved temporally along the horizontal meridian to the point at which it could be seen most clearly. The highest visibility was attained at a point approximately 25° from the center of the arc. This, it will be remembered, was the point in the field at which there was the smallest error refraction, 0.5 diopter simple hyperopic astigmatism. With the fixation-object at this point a fairly satisfactory control of fixation was secured and a map of the blind-spot was made. The location of the fixation-object and the map of the blind-spot are shown in Fig. 8.

A phenomenon of very great theoretical and practical interest observed during the course of the work may be noted here. During the early part of the work of the examination at the different point in the peripheral field was made by taking an eccentric fixation, the instrument remaining stationary. One of the reasons for abandoning this method of working was the fact that when the fixation was held for any appreciable length of time, the eyes of the class we have called Type A developed an increased myopia in the horizontal meridian with a corresponding decrease in the hyperopia for the vertical meridian. With prolonged fixation this change in some cases amounted to as much as 2.5 diopters. A similar tendency in the same direction was shown also by eyes of the class we have called Type B. Further, when the method was changed and a far fixation was taken in the median plane—the examination at the peripheral points in the field being made by rotating the apparatus about the fixed point described in the method of working—the phenomenon was still present in some eyes but to a lesser degree. There seem to be two possibilities of explaining the phenomenon: (a) a change in the convexity of the lens, and (b) the possibility that as the fixation is prolonged the muscles of the eye gradually produce an elongation of the eyeball.[3] The first of these explanations does not seem plausible because the rendering of the eye myopic by a change in

[3] It is assumed here that the eyes are under considerable pressure from the external muscles in a prolonged eccentric fixation, the amount depending upon the degree of eccentricity. It is also assumed that they are under some pressure in taking and holding far fixation in the median plane; that is, when relaxed and freed from all incentives to adjustment for clear seeing, as is the case with closed lids and in the dark, the eyes take a more converging position.

the focus of the lens would operate against the clear seeing of the fixation-object. This would be in opposition to one of the eye's strongest reflex incentives; namely, the adjustment of its refracting mechanism to produce the clearest possible vision; while the gradual elongation of the eyeball because of the pressure exerted by the external muscles in maintaining fixation, falls entirely outside the reflex and is unavoidable.

To test the point, the examination was made under as profound a cycloplegic as could be obtained with atropine. The performance of the Zeiss refractionometer is, it may be noted, not as satisfactory with as without a cycloplegic. With wide expansion of the pupil, produced by the cycloplegic, the test images that are formed by the refracting system of the eye are not nearly so clear and distinct as they are with smaller pupils. This affords another interesting example of the poor and unnatural performance of the refraction system of the eye with an expanded pupil. It was found possible, however, to make the examination under cycloplegic with a fair degree of satisfaction. The phenomenon was still present, but in a diminished amount.

In connection with the phenomenon two points of interest may be noted: (a) there is a bearing on the possibility of a permanent elongation of the eyeball by the pressure of the external muscles, one of the theories of the cause of myopia; and (b) the phenomenon strongly suggests that a temporary elongation may be produced in some eyes, presumably due to the action of the external muscles. This is of interest in connection with theories of accommodation and with the ability of certain aphacic eyes to see near objects with the same correction that is used for seeing distant objects.

Summary and Conclusions

(1) The refraction of the eye in the temporal and nasal peripheral field as far out as 60° has been studied by means of a Zeiss refractionometer modified to suit the purpose. Twenty-one eyes have been examined. Those selected included eyes with a slight central error of refraction and eyes with a pronounced central error of refraction.

(2) The eyes examined fall into three classes. In Type A, the eye becomes more myopic in the horizontal plane as the periphery of the field is approached and more hyperopic in the vertical plane. In all eyes examined but one (in which there was a high myopic astigmatism in the central field), this resulted in a mixed astigmatism in the peripheral field, the interval of Sturm varying over a considerable range of diopters. In Type B, the eye becomes less myopic in the horizontal plane and more hyperopic in the vertical plane. This results in a condition of compound hyperopic astigmatism in the peripheral field for eyes that are hyperopic, emmetropic

and moderately myopic in the central field. If there is strong myopia at the center of the field, it is obviously possible that a compound myopic astigmatism might result over the greater part of the peripheral field, weakening in amount as the periphery is approached. In Type C, the refractive condition is asymmetrical for the nasal and temporal halves of the field. The general trend of this asymmetry, as the periphery of the field is approached, is towards greater myopia and less hyperopia for one half of the field than for the other half.

(3) As fixation was prolonged, a tendency toward myopia was found; that is, if hyperopic, the eye tended to become less hyperopic; if emmetropic, it tended to become myopic; and if myopic, more myopic. This change was found to take place in all the eyes examined when an eccentric fixation was taken; also for some eyes when a far fixation was taken in the median plane. Further, the change was found to take place whether the examination was made with or without a cycloplegic. Two points of interest may be noted in connection with this phenomenon: (a) there is a bearing on the possibility that a permanent elongation of the eyeball may be produced by the pressure of the muscles, one of the theories of the cause of myopia; and (b) the phenomenon suggests that a temporary elongation may be produced in some eyes, presumably due to the action of the external muscles. This is of interest in connection with theories of accommodation and with the ability of some aphacic eyes to see near objects with the same correction that is used for seeing distant objects.

(4) The following additional points may be noted: (a) the important relation which the refractive conditions in the peripheral field sustain to acuity in the peripheral field, to achromatic and chromatic sensitivity in peripheral vision and the limits of the form and color fields, and to the anomalies and irregularities in peripheral space perception. The conditions for the formation of an image are so bad for objects in the peripheral field that one can only marvel that peripheral vision is as good as it is, and that the peripheral portions of the retina should have attained as high a development as they have.

(b) The possible bearing of asymmetrical refraction in the peripheral field on the explanation of cases in which central vision can not be substantially improved by correction in eyes which show no central scotoma.

(c) The rôle which asymmetrical refraction may play in cases of ocular deviation and the bearing that the demonstration of such a condition may have on the treatment of the case.

(d) The possibility of determining roughly the conformation of the retina and the shape of the posterior half of the eyeball by refracting the eye for the peripheral field; also of determining within rather wide limits in cases of refractive asymmetry whether the defect is in the refracting system, or in the conformation of the retina, or in both.

(e) The possibility and comparative practicability of using the Zeiss refractionometer, modified as described in this paper, for studying the refractive conditions in the peripheral field and in testing for refractive asymmetry. To give the instrument maximum serviceability for this purpose, however, a further modification should be devised to make the examination possible and feasible for the upper and lower as well as for the temporal and nasal halves of the field. Cases which might be tested to advantage for refractive asymmetry as clinic procedure are those in which a pronounced ocular deviation is combined with low central vision and there is no detectable scotoma.

It is stated above that one marvels that vision in the peripheral portions of the field is as good as it proves to be. In fact when one considers the type of image that is formed in case of an axial astigmatism, an astigmatism of incidence or a lens out of focus, in comparison with the power of vision that is actually present under these conditions, one is almost inclined to concede a supplementary resolving power to the rods and cones themselves. Some of the additional phenomena that seem to need explanation are: (1) the power of vision in general in ametropic eyes; (2) the power of vision in the peripheral field; (3) the power of seeing objects nearer and farther than the fixation-point; (4) the contention by Ames and Gliddon that the actual accommodation distance in viewing objects does not coincide with the apparent accommodation distance;[4] (5) the power which some aphacic eyes have of seeing objects at all distances with the same pair of glasses; (6) the effect of increase of intensity of illumination on acuity and the much greater effect on ametropic than on emmetropic eyes; and (7) the phenomenon of relative accommodation, on the power of separating accommodation from convergence without impairing vision, and the increase in this power with increase of intensity of illumination.

[4] A. Ames, Jr., and G. H. Gliddon, Ocular measurements, *Trans. Amer. Med. Assoc., Section on Ophth.*, 1928, 102-169.